CERTIFICATION

I, Yoshihiko Takeda, 10-1 Higashikotari 1-chome, Nagaokakyo-shi, Kyoto-fu, Japan 617-8555, do hereby certify that I am conversant in the English language and the Japanese language, and I further certify that, to the best of my knowledge and belief, the attached English translation is a true and correct translation of Japanese Patent Application No. 2002-325672 filed on November 8, 2002.

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[Title of the Invention] BRANCHING FILTER

[Claims]

[Claim 1]

A branching filter comprising a transmission-side filter and a reception-side filter in which piezoelectric resonators including at least one piezoelectric thin film sandwiched between at least one pair of facing electrodes are disposed in a ladder type on an opening or a recess of a substrate, the transmission-side filter and the reception-side filter being connected to an antenna terminal in parallel,

wherein the piezoelectric resonators constituting the transmission-side filter and the piezoelectric resonators constituting the reception-side filter have a different structure.

[Claim 2]

The branching filter according to claims 1, wherein the piezoelectric resonators constituting the transmission-side filter and the piezoelectric resonators constituting the reception-side filter comprise a different insulating film on the opening or the recess of the substrate.

[Claim 3]

The branching filter according to claim 2, wherein the insulating film of the piezoelectric resonators constituting

the reception-side filter comprises SiO_2.

[Claim 4]

The branching filter according to claim 2, wherein the insulating film of the piezoelectric resonators constituting the reception-side filter comprises two layers including a SiO_2 layer and an Al_2O_3 layer that are provided in that order from the side nearer to the piezoelectric thin film.

[Claim 5]

The branching filter according to claim 2, wherein the insulating film of the piezoelectric resonators constituting the reception-side filter comprises two layers including a SiO_2 layer and an AlN layer that are provided in that order from the side nearer to the piezoelectric thin film.

[Claim 6]

The branching filter according to any one of claims 2 to 5, wherein the insulating film of the piezoelectric resonators constituting the transmission-side filter comprises two layers including an AlN layer and a SiO_2 layer that are provided in that order from the side nearer to the piezoelectric thin film.

[Claim 7]

The branching filter according to any one of claims 2 to 5, wherein the insulating film of the piezoelectric resonators constituting the transmission-side filter comprises two layers including an Al_2O_3 layer and a SiO_2

layer that are provided in that order from the side nearer to the piezoelectric thin film.

[Claim 8]

The branching filter according to any one of claims 1 to 7, wherein the piezoelectric resonators constituting the transmission-side filter and the piezoelectric resonators constituting the reception-side filter comprise a different piezoelectric film.

[Claim 9]

The branching filter according to claim 8, wherein the piezoelectric film of the piezoelectric resonators constituting the transmission-side filter comprises AlN, and the piezoelectric film of the piezoelectric resonators constituting the reception-side filter comprises ZnO.

[Claim 10]

The branching filter according to any one of claims 1 to 9, wherein the material of the electrodes is different between the piezoelectric resonators constituting the transmission-side filter and the piezoelectric resonators constituting the reception-side filter.

[Detailed Description of the Invention]

[0001]

[Technical Field of the Invention]

The present invention relates to a branching filter that is used in a communication device or the like and that

includes filters having piezoelectric thin film resonators.

[0002]

[Description of the Related Art]

In recent years, piezoelectric thin film filters using elastic bulk waves have been developed. The above piezoelectric thin film filters are compact in size, have light weight, and are excellent in vibration resistance and impact resistance. In addition, the piezoelectric thin film filters have small variation in products and high reliability, and can provide non-adjusting circuits. Therefore, the mounting can be automated and simplified. Furthermore, even when the frequency is increased, the piezoelectric thin film filters can be easily produced. Thus, the piezoelectric thin film filters have superior characteristics.

[0003]

A branching filter (duplexer) including such piezoelectric thin film filters has been proposed. For example, Patent Document 1 discloses a branching filter including piezoelectric thin film filters in which piezoelectric thin film resonators are arranged in a ladder type. The piezoelectric resonators used in the branching filter disclosed in Patent Document 1 form a transmission-side filter and a reception-side filter. In both filters, electrodes are composed of Mo and piezoelectric thin films

are composed of AlN.

[0004]

[Patent Document 1]

Japanese Unexamined Patent Application Publication No. 2001-24476

[0005]

[Problems to be Solved by the Invention]

However, the required characteristics are different between the transmission-side filter and the reception-side filter in the branching filter. That is, piezoelectric thin film resonators having the same structure are optimized only in either the transmission-side filter or the reception-side filter. According to Patent Document 1, both the transmission-side filter and the reception-side filter have the same structure. Therefore, a branching filter having optimum characteristics in both transmission side and reception side cannot be achieved.

[0006]

In view of the above problems, it is an object of the present invention to provide a branching filter having satisfactory characteristics in which the structures of a transmission-side filter and a reception-side filter are optimized.

[0007]

[Means for Solving the Problems]

In order to solve the above problems, a branching filter of the present invention includes a transmission-side filter and a reception-side filter in which piezoelectric resonators including at least one piezoelectric thin film sandwiched between at least one pair of facing electrodes are disposed in a ladder type on an opening or a recess of a substrate, the transmission-side filter and the reception-side filter being connected to an antenna terminal in parallel. In the branching filter, the piezoelectric resonators constituting the transmission-side filter and the piezoelectric resonators constituting the reception-side filter have a different structure.

[0008]

In the branching filter of the present invention, in addition to the above structure, the piezoelectric resonators constituting the transmission-side filter and the piezoelectric resonators constituting the reception-side filter preferably include a different insulating film on the opening or the recess of the substrate.

[0009]

According to the above structure, the transmission-side filter and the reception-side filter include piezoelectric resonators having different structures from each other. As a result, a branching filter having optimum characteristics in both the transmission-side filter and the reception-side

filter can be provided.

[0010]

In the branching filter of the present invention, the insulating film of the piezoelectric resonators constituting the reception-side filter is preferably composed of SiO_2.

[0011]

In the branching filter of the present invention, the insulating film of the piezoelectric resonators constituting the reception-side filter is preferably composed of two layers including a SiO_2 layer and an Al_2O_3 layer that are provided in that order from the side nearer to the piezoelectric thin film.

[0012]

In the branching filter of the present invention, the insulating film of the piezoelectric resonators constituting the reception-side filter is preferably composed of two layers including a SiO_2 layer and an AlN layer that are provided in that order from the side nearer to the piezoelectric thin film.

[0013]

In the branching filter of the present invention, the insulating film of the piezoelectric resonators constituting the transmission-side filter is preferably composed of two layers including an AlN layer and a SiO_2 layer that are provided in that order from the side nearer to the

piezoelectric thin film.

[0014]

In the branching filter of the present invention, the insulating film of the piezoelectric resonators constituting the transmission-side filter is preferably composed of two layers including an Al_2O_3 layer and a SiO_2 layer that are provided in that order from the side nearer to the piezoelectric thin film.

[0015]

In the branching filter of the present invention, the piezoelectric resonators constituting the transmission-side filter and the piezoelectric resonators constituting the reception-side filter preferably include a different piezoelectric film.

[0016]

In the branching filter of the present invention, the piezoelectric film of the piezoelectric resonators constituting the transmission-side filter is preferably composed of AlN, and the piezoelectric film of the piezoelectric resonators constituting the reception-side filter is preferably composed of ZnO.

[0017]

In the branching filter of the present invention, the material of the electrodes is preferably different between the piezoelectric resonators constituting the transmission-

side filter and the piezoelectric resonators constituting the reception-side filter.

[0018]

[Description of the Embodiments]

[First Embodiment]

An embodiment of the present invention will now be described with reference to Figs. 1 to 4. In the present embodiment, a duplexer in which the transmission band is 1,850 to 1,910 MHz and the reception band is 1,930 to 1,990 MHz will now be described.

[0019]

As shown in Fig. 1, the duplexer (branching filter) according to the present embodiment includes a transmitting terminal 1, a receiving terminal 2, and an antenna terminal 3. The duplexer includes a transmission-side filter 5, a reception-side filter 6, and a matching circuit 7. The transmission-side filter 5 is disposed between the antenna terminal 3 and the transmitting terminal 1. The reception-side filter 6 is disposed between the antenna terminal 3 and the receiving terminal 2. The matching circuit 7 is disposed between the antenna terminal 3 and the reception-side filter 6. That is, in this duplexer, the transmission-side filter 5 and the reception-side filter 6 are connected to the antenna terminal 3 in parallel. A capacitance 8 is disposed between the antenna terminal 3 and the

transmission-side filter 5. The passband in the transmission-side filter 5 and that in the reception-side filter 6 are set so as to be different from each other.

[0020]

The transmission-side filter 5 includes series resonators 11a and 11b and parallel resonators 12a and 12b in a ladder type. The parallel resonators 12a and 12b are grounded through inductances 13a and 13b. The inductances 13a and 13b can extend the passband of the transmission-side filter 5.

[0021]

The reception-side filter 6 includes series resonators 21a, 21b, and 21c and parallel resonators 22a, 22b, 22c, and 22d in a ladder type. The parallel resonators 22a, 22b, 22c, and 22d are grounded.

[0022]

The matching circuit 7 includes an inductance 71 connected in series and capacitances 72 and 73 connected in parallel.

[0023]

In the present embodiment, the resonators in the transmission-side filter 5 and the reception-side filter 6 are piezoelectric resonators. Each of the piezoelectric resonators includes a thin film (piezoelectric thin film) composed of a piezoelectric material and electrodes that

sandwich the piezoelectric thin film and face each other.

[0024]

The characteristics desired for the transmission-side filter 5 and the reception-side filter 6 wherein the transmission-side filter has relatively low frequency characteristics and the reception-side filter has relatively high frequency characteristics will now be described.

[0025]

A large electric power is applied to the transmission-side filter 5. Therefore, the resonators used in the transmission-side filter 5 preferably have a high Q factor. This Q factor represents the mechanical vibration loss in the resonator. Since a low Q factor increases the mechanical vibration loss in the resonator, the loss causes heat and the resonator generates heat. As a result, the lifetime of the resonator is shortened. Furthermore, the lifetime of the transmission-side filter 5 is also shortened. The Q factor depends on the structure of the resonator. Furthermore, the smaller the elastic loss of the material used in the resonator, the higher the Q factor. Since the elastic loss of materials also depends on the frequency etc., it is difficult to mention the specific values. However, propagation loss, which is often used in, for example, a surface acoustic wave device, is an indicator. That is, it is believed that the smaller the propagation loss of the

material used in the resonator, the larger the Q factor of the resonator.

[0026]

A material having a high thermal conductivity is preferably used as the resonators in the transmission-side filter 5. The reason for this is as follows: A low thermal conductivity decreases the heat dissipation effect. As a result, the resonator is heated and the lifetime of the resonator is shortened.

[0027]

The electromechanical coupling coefficient k^2 (effective coupling coefficient k^2_{eff}) of the resonators in the transmission-side filter 5 is preferably in the range of about 3% to 4%. The reason for this is as follows: Even when the electromechanical coupling coefficient k^2_{eff} is small, the passband can be extended to the low frequency side to some extent with an external circuit (for example, an extended inductance). When the electromechanical coupling coefficient k^2_{eff} is 5% or more, roll-off characteristics at the high frequency side (i.e., the steepness of the attenuation in the range from the passband of 1,910 MHz in the transmission side to the passband of 1,930 MHz in the reception side) is degraded. The use of a material having a large electromechanical coupling coefficient k^2 as the piezoelectric thin film increases the k^2_{eff} of the resonator.

The electromechanical coupling coefficient k^2_{eff} also depends on the structure of the resonator.

[0028]

In the reception-side filter 6, when the passband is extended to the low frequency side with an external circuit, the reception-side filter 6 interferes with the transmission-side filter 5. In addition, an external circuit cannot extend the passband to the high frequency side. For these reasons, in the reception-side filter 6, a predetermined filter band must be ensured using resonators having a large electromechanical coupling coefficient k^2_{eff} and without using an auxiliary external circuit.

[0029]

The structures of the piezoelectric resonator of the transmission-side filter 5 and the piezoelectric resonator of the reception-side filter 6 having the above characteristics will now be described in detail with reference to Figs. 2 and 3.

[0030]

As shown in Fig. 2, a resonator of the transmission-side filter 5 includes a supporting substrate (substrate) 32 composed of silicon (Si) and an insulating film 31 disposed on the supporting substrate 32. Furthermore, the supporting substrate 32 includes an opening (hollow part) that penetrates the supporting substrate 32 in the direction of

the thickness and extends to the other side of the insulating film 31. A lower electrode (electrode) 33, a piezoelectric thin film 34, and an upper electrode (electrode) 35 are disposed on the insulating film 31 in that order. The insulating film 31 forms a diaphragm. This diaphragm faces the opening (hollow part).

[0031]

As shown in Fig. 3, a resonator of the reception-side filter 6 includes a supporting substrate (substrate) 42 composed of silicon (Si) and an insulating film 41 disposed on the supporting substrate 42. Furthermore, the supporting substrate 42 includes an opening (hollow part) that penetrates the supporting substrate 42 in the direction of the thickness and extends to the insulating film 41. A lower electrode 43, a piezoelectric thin film 44, and an upper electrode 45 are disposed on the insulating film 41 in that order.

[0032]

The insulating film 41 forms a diaphragm. This diaphragm faces the opening (hollow part).

[0033]

In the present embodiment, the type of the piezoelectric thin film is different between the resonators of the transmission-side filter 5 and the resonators of the reception-side filter 6. In the resonators of the

transmission-side filter 5, the piezoelectric thin film 34 is composed of AlN, the insulating film 31 is composed of SiO_2, and the lower electrode 33 and the upper electrode 35 are composed of Au/Ti. In the resonators of the reception-side filter 6, the piezoelectric thin film 45 is composed of ZnO, the insulating film 41 is composed of SiO_2, and the lower electrode 43 and the upper electrode 45 are composed of Au/Ti.

[0034]

The resonators of the transmission-side filter 5 will now be described in more detail. Aluminum nitride (AlN) has a thermal conductivity higher than that of ZnO and has an elastic loss smaller than that of ZnO. Aluminum nitride (AlN) has a small electromechanical coupling coefficient (k_t = 0.23, thermal conductivity W/(m·°C) = 150). Accordingly, the resonators of the transmission-side filter 5 have a Q factor and a heat dissipation effect higher than those of the resonators of the reception-side filter 6.

[0035]

Furthermore, in the resonators of the transmission-side filter 5, the insulating film 31 composed of SiO_2 is used. Therefore, the sign of the temperature coefficient of the insulating film 31 composed of SiO_2 and that of the piezoelectric thin film 34 composed of AlN are opposite with respect to each other. Therefore, a temperature change is

cancelled out in the piezoelectric thin film 34 and the insulating film 31. As a result, the temperature characteristics in the resonators of the transmission-side filter 5 can be improved.

[0036]

The acoustic velocity in AlN is larger than that in ZnO. In order to obtain the equivalent frequency as that of the resonator including ZnO, the film thickness of the diaphragm must be increased or an electrode material having a large density must be used. When the film thickness of AlN is increased, the area (vibration part) where the upper electrode 35 overlaps with the lower electrode 33 must be increased in order that the capacitance (C_0) of the resonator is controlled to be a predetermined value. As a result, the element size is increased. However, a metal having a density of at least 8 g/cm^3 (for example, Au: 19.3, Pt: 21.45, Ni: 8.9, and Mo: 10.4) can be used as at least one of the upper electrode 33 and the lower electrode 35. In this case, the predetermined frequency can be obtained without increasing the area of the upper electrode 33 or the lower electrode 35.

[0037]

The resonators of the reception-side filter 6 will now be described in more detail. Zinc oxide (ZnO) has an electromechanical coupling coefficient larger than that of

AlN (k_t = 0.30). Accordingly, the resonators of the reception-side filter 6 have a large electromechanical coupling coefficient k^2_{eff}. Zinc oxide (ZnO) has a thermal conductivity lower than that of AlN (thermal conductivity W/(m·°C) = 4).

[0038]

Furthermore, in the resonators of the reception-side filter 6, the insulating film 41 composed of SiO_2 is used. Therefore, the sigh of the temperature coefficient of the insulating film 41 composed of SiO_2 and that of the piezoelectric thin film 44 composed of ZnO are opposite with respect to each other. Therefore, a temperature change is cancelled out in the piezoelectric thin film 44 and the insulating film 41. As a result, the temperature characteristics in the resonators of the reception-side filter 6 can be improved.

[0039]

In the resonators of the transmission-side filter 5, AlN having a small electromechanical coupling coefficient k^2 is used as the piezoelectric thin film 34. Therefore, the electromechanical coupling coefficient k^2_{eff} of the resonators of the transmission-side filter is smaller than that of the resonators of the reception-side filter. As shown in Fig. 1, the inductances 13a and 13b are connected to the parallel resonators 12a and 12b of the transmission-side filter 5.

Therefore, in this case, the passband can be extended to the low frequency side, thereby obtaining the desired bandwidth.

[0040]

[Second Embodiment]

An embodiment of the present invention will now be described with reference to Figs. 4 to 8. For the convenience of description, components having the same function as those of the components shown in the first embodiment have the same reference numerals and the description is omitted.

[0041]

In the present embodiment, as shown in Fig. 4, an insulating film 41 in the resonators of the reception-side filter 6 is composed of two layers: An insulating film 41a is disposed on a substrate 42 and an insulating film 41b is disposed on the insulating film 41a.

[0042]

In the present embodiment, the insulating film 41a is preferably composed of Al_2O_3, and the insulating film 41b is preferably composed of SiO_2. In this structure, a compressive stress is applied on the piezoelectric thin film 44 composed of ZnO and the insulating film 41b composed of SiO_2, whereas a tensile stress is applied on the insulating film 41a composed of Al_2O_3. This structure can stabilize the strength of the diaphragm.

[0043]

In the present embodiment, the insulating film 41a may be composed of AlN. In this case, the sigh of the temperature coefficient of the insulating film 41a composed of AlN and that of the insulating film 41b composed of SiO_2 are opposite with respect to each other. Therefore, a temperature change is cancelled out in the insulating film 41a and the insulating film 41b. As a result, the temperature characteristics in the resonators of the reception-side filter 6 can be improved. Furthermore, since AlN has excellent thermal conductivity compared with Al_2O_3, the heat dissipation effect can be improved.

[0044]

The above structure can increase the electromechanical coupling coefficient k^2_{eff}. This is because the acoustic impedance of SiO_2 constituting the insulating film 41b is 1.3×10^7 ($N \cdot s/m^3$), which is smaller than that of ZnO (3.5×10^7 ($N \cdot s/m^3$)) constituting the piezoelectric thin film 44, that of Al_2O_3 (3.9×10^7 ($N \cdot s/m^3$)) constituting the insulating film 41a, and that of AlN (3.5×10^7 ($N \cdot s/m^3$)) constituting the insulating film 41a. That is, acoustic waves are significantly reflected at the interface between the piezoelectric thin film 44 and the insulating film 41b, and the energy of the acoustic waves is concentrated on the piezoelectric thin film 44. Accordingly, the

electromechanical coupling coefficient k^2_{eff} can be increased. As shown in the displacement diagram of vibration in Fig. 5, the displacement of vibration in ZnO of the piezoelectric thin film 44 is larger than that in SiO_2 of the insulating film 41b.

[0045]

The thicknesses of the piezoelectric thin film 44, the insulating film 41a composed of Al_2O_3, and the insulating film 41b composed of SiO_2 will now be described. As shown in Fig. 6, in terms of a large electromechanical coupling coefficient k^2_{eff}, the film thickness ratio represented by the thickness of the piezoelectric thin film 44 : (the thickness of the insulating film 41a composed of Al_2O_3 + the thickness of the insulating film 41b composed of SiO_2) is preferably in the range of 0.7 to 1.3. Furthermore, as shown in Fig. 7, in terms of a large Q factor, the film thickness ratio is preferably in the range of 0.6 to 0.8. As shown in Fig. 8, in terms of a small absolute value of the temperature coefficient of frequency (TCF), the film thickness ratio represented by the insulating film 41a (Al_2O_3) : the insulating film 41b (SiO_2) is preferably 1 or more. However, when the ratio of the insulating film 41a to the insulating film 41b is excessively small, the problem of stress balance occurs. Therefore, the film thickness ratio represented by the insulating film 41a (Al_2O_3) : the insulating film 41b

(SiO_2) is more preferably in the range of 1 to 3.

[0046]

In Figs. 6 to 8, the piezoelectric thin film 44 is composed of ZnO, the insulating film 41a is composed of Al_2O_3, and the insulating film 41b is composed of SiO_2. The upper electrode 43 and the lower electrode 45 that sandwich the piezoelectric thin film 44 are composed of Al and have a film thickness of 180 nm. The figures show the calculation results in which the film thickness ratio of the insulating film 41b (SiO_2) to the insulating film 41a (Al_2O_3) is varied from 3:1 to 1:3 under the above conditions. The absolute amount of each film thickness is determined such that the frequency band of the resonators is controlled to be 1,900 MHz.

[0047]

[Third Embodiment]

An embodiment of the present invention will now be described with reference to Figs. 9 to 17. For the convenience of description, components having the same function as those of the components shown in the first embodiment and the second embodiment have the same reference numerals and the description is omitted.

[0048]

In the present embodiment, as shown in Fig. 9, an insulating film 31 in the resonators of the transmission-

side filter 5 is composed of two layers: An insulating film 31a is disposed on a substrate 32 and an insulating film 31b is disposed on the insulating film 31a.

[0049]

In the present embodiment, the insulating film 31a is preferably composed of SiO_2 and the insulating film 31b is preferably composed of AlN. In this case, since AlN has excellent thermal conductivity, the heat dissipation effect of the element can be improved. This structure can achieve high withstand power, extend the lifetime, and improve the reliability of the element.

[0050]

In the present embodiment, the insulating film 31a may be composed of SiO_2 and the insulating film 31b may be composed of Al_2O_3. In this structure, a compressive stress is applied on the insulating film 31a composed of SiO_2, whereas a tensile stress is applied on the insulating film 31b composed of Al_2O_3. This structure can stabilize the strength of the diaphragm.

[0051]

The above structure can decrease the absolute value of the temperature coefficient of frequency (TCF). The reason for this is as follows: The temperature coefficient of ZnO, Al_2O_3, and AlN that are used as the piezoelectric thin film 34 or the insulating film 31b is negative (i.e., the rise in

temperature decreases the frequency). On the other hand, the temperature coefficient of SiO_2 used as the insulating film 31a is positive. As shown in the displacement diagram of vibration in Fig. 10 (wherein ZnO is used as the piezoelectric thin film 34), it is believed that the displacement of vibration in ZnO of the piezoelectric thin film 34 is strongly affected by the temperature coefficient of SiO_2 constituting the insulating film 31a, and thus the TCF of the whole resonator is shifted in the positive direction (i.e., comes close to zero).

[0052]

When the above piezoelectric thin film 34, the insulating film 31a composed of SiO_2, and the insulating film 31b composed of Al_2O_3 are used, the thicknesses of the insulating film 31a and the insulating film 31b are preferably as follows. Since the dependency to the thickness of the piezoelectric thin film 34 is small, the film thickness ratio is not particularly limited. However, as shown in Figs. 11 and 12, in terms of a large electromechanical coupling coefficient k^2_{eff} and a large Q factor, the film thickness ratio represented by the thickness of the piezoelectric thin film 34 : (the thickness of the insulating film 31a composed of SiO_2 + the thickness of the insulating film 31b composed of Al_2O_3) is preferably in the range of 0.7 to 1.2. As shown in Fig. 13, in terms

of a small absolute value of the temperature coefficient of frequency (TCF), the film thickness ratio represented by the insulating film 31a (SiO_2) : the insulating film 31b (Al_2O_3) is preferably 1 or more. However, when the ratio of the insulating film 31a (SiO_2) to the insulating film 31b (Al_2O_3) is excessively small, the problem of stress balance occurs. Therefore, the film thickness ratio represented by the insulating film 31a (SiO_2) : the insulating film 31b (Al_2O_3) is more preferably in the range of 1 to 3.

[0053]

In Figs. 11 to 13, the piezoelectric thin film 34 is composed of ZnO, the insulating film 31a is composed of SiO_2, and the insulating film 31b is composed of Al_2O_3. The upper electrode 33 and the lower electrode 35 that sandwich the piezoelectric thin film 34 are composed of Al and have a film thickness of 180 nm. The figures show the calculation results in which the film thickness ratio of the insulating film 31b (Al_2O_3) to the insulating film 31a (SiO_2) is varied from 3:1 to 1:3 under the above conditions. The absolute amount of each film thickness is determined such that the frequency band of the resonators is controlled to be 1,900 MHz.

[0054]

As shown in Fig. 14, the reception-side filter may include two series resonators and three parallel resonators.

As shown in Fig. 15, in the transmission-side filter, a resonator may be added in series adjacent to the transmission side terminal. The matching circuit may include two inductances connected in series and a capacitance connected in parallel. Furthermore, the capacitance 8 may be omitted. As shown in Fig. 16, each of the series resonators in the transmission-side filter in Fig. 14 may be replaced with two series resonators.

[0055]

A modification of the resonator in the transmission-side filter 5 and the reception-side filter 6 will now be described with reference to Fig. 17. As shown in Fig. 17, the resonator includes an insulating film 51 on a recess 56 provided on a substrate 52. The insulating film 51 is suspended over the recess 56 at the periphery. A lower electrode 53, a piezoelectric thin film 54, and an upper electrode 55 are disposed on the insulating film 51. The above-described structures of the piezoelectric thin film and the insulating film in the transmission-side filter 5 and the reception-side filter 6 can be applied to this structure. Thus, the same advantages as those in the above-described structures can be achieved in this structure.

[0056]

In addition, when the resonators of the transmission-side filter 5 and the resonators of reception-side filter 6

are composed of the same materials and are different only in the deposited order, the same deposition equipment can be used to reduce the cost.

[0057]

The use of the transmission-side filter 5 including resonators having a piezoelectric thin film 34 composed of ZnO, an insulating film 31a composed of SiO_2, and an insulating film 31b composed of AlN can achieve a Q factor of 700 and an electromechanical coupling coefficient k^2_{eff} of 2.9%. The use of the reception-side filter 6 including resonators having a piezoelectric thin film 44 composed of ZnO, an insulating film 41a composed of Al_2O_3, and an insulating film 41b composed of SiO_2 can achieve a Q factor of 400 and an electromechanical coupling coefficient k^2_{eff} of 5.3%. Figs. 18 and 19 show the frequency characteristics of insertion loss in the transmission-side filter 5 and the reception-side filter 6. In the transmission-side filter 5, the inductances are connected to the parallel resonators. Therefore, as shown in Figs. 18 and 19, the bandwidth can be extended to the low frequency side despite the small electromechanical coupling coefficient k^2_{eff}. In contrast, in the reception-side filter 6, the bandwidth can be increased because of the large electromechanical coupling coefficient k^2_{eff}. As shown in Fig. 19, regarding the bandwidth wherein the level is attenuated by 3.5 dB, the transmission-side

filter 5 can provide the bandwidth of 80 MHz, and the reception-side filter 6 can provide the bandwidth of 68 MHz.

[0058]

As a comparative example, a reception-side filter 6 including resonators having a piezoelectric thin film 44 composed of ZnO, an insulating film 41a composed of SiO_2, and an insulating film 41b composed of AlN is used. The resonators have a Q factor of 700 and an electromechanical coupling coefficient k^2_{eff} of 2.9%. As shown in Figs. 20 and 21, in this reception-side filter 6, the bandwidth wherein the level is attenuated by 3.5 dB is no more than 36 MHz.

[0059]

The present invention is not limited to the above-described embodiments and various modifications are possible within the scope described in the claims. The technical field of the present invention also includes embodiments obtained by appropriately combining technical methods disclosed in the different embodiments.

[0060]

[Advantages of the Invention]

As described above, the branching filter of the present invention includes a transmission-side filter and a reception-side filter wherein piezoelectric resonators including at least one piezoelectric thin film sandwiched between at least one pair of facing electrodes are disposed

in a ladder type on an opening or a recess of a substrate, the transmission-side filter and the reception-side filter being connected to an antenna terminal in parallel. In the branching filter, the piezoelectric resonators constituting the transmission-side filter and the piezoelectric resonators constituting the reception-side filter have a different structure.

[0061]

According to the above structure, the transmission-side filter and the reception-side filter include piezoelectric resonators having different structures from each other. As a result, a branching filter having optimum characteristics in both the transmission-side filter and the reception-side filter can be advantageously provided.

[Brief Description of the Drawings]

[Fig. 1]

Fig. 1 is a circuit diagram of a duplexer according to an embodiment of the present invention.

[Fig. 2]

Fig. 2 is a schematic cross-sectional view showing the structure of a resonator of a transmission-side filter in the duplexer.

[Fig. 3]

Fig. 3 is a schematic cross-sectional view showing the structure of a resonator of a reception-side filter in the

duplexer.

[Fig. 4]

Fig. 4 is a schematic cross-sectional view showing the structure of a resonator of a reception-side filter according to an embodiment of the present invention.

[Fig. 5]

Fig. 5 is a graph showing the displacement of vibration of each layer in an example of the resonator shown in Fig. 4.

[Fig. 6]

Fig. 6 is a graph showing the relationship between the electromechanical coupling coefficient k^2_{eff} and the film thickness ratio in the resonator shown in Fig. 4.

[Fig. 7]

Fig. 7 is a graph showing the relationship between the Q factor and the film thickness ratio in the resonator shown in Fig. 4.

[Fig. 8]

Fig. 8 is a graph showing the relationship between the temperature coefficient of frequency (TCF) and the film thickness ratio in the resonator shown in Fig. 4.

[Fig. 9]

Fig. 9 is a schematic cross-sectional view showing the structure of the resonator in a transmission-side filter according to an embodiment of the present invention.

[Fig. 10]

Fig. 10 is a graph showing the displacement of vibration of each layer in an example of the resonator shown in Fig. 9.

[Fig. 11]

Fig. 11 is a graph showing the relationship between k^2_{eff} and the film thickness ratio in the resonator shown in Fig. 9.

[Fig. 12]

Fig. 12 is a graph showing the relationship between the Q factor and the film thickness ratio in the resonator shown in Fig. 9.

[Fig. 13]

Fig. 13 is a graph showing the relationship between TCF and the film thickness ratio in the resonator shown in Fig. 9.

[Fig. 14]

Fig. 14 is a circuit diagram showing a modification of the duplexer.

[Fig. 15]

Fig. 15 is a circuit diagram showing a modification of the duplexer.

[Fig. 16]

Fig. 16 is a circuit diagram showing a modification of the duplexer.

[Fig. 17]

Fig. 17 is a schematic cross-sectional view showing a modification of the resonator in the transmission-side filter and the reception-side filter.

[Fig. 18]

Fig. 18 is a graph showing the frequency characteristics of insertion loss in a transmission-side filter and a reception-side filter according to an embodiment of the present invention.

[Fig. 19]

Fig. 19 is a graph showing the frequency characteristics of insertion loss in the transmission-side filter and the reception-side filter according to the embodiment of the present invention.

[Fig. 20]

Fig. 20 is a graph showing the frequency characteristics of insertion loss in a transmission-side filter and a reception-side filter in a comparative example.

[Fig. 21]

Fig. 21 is a graph showing the frequency characteristics of insertion loss in the transmission-side filter and the reception-side filter in the comparative example.

[Reference Numerals]

1: transmitting terminal

2: receiving terminal

3: antenna terminal

5: transmission-side filter

6: reception-side filter

11a and 11b: series resonator

12a and 12b: parallel resonator

13a and 13b: inductance

21a to 21c: series resonator

22a to 22d: parallel resonator

31: insulating film

32: supporting substrate (substrate)

33: lower electrode (electrode)

34: piezoelectric thin film

35: upper electrode (electrode)

41: insulating film

42: supporting substrate (substrate)

43: lower electrode (electrode)

44: piezoelectric thin film

45: upper electrode (electrode)

[Name of Document] ABSTRACT

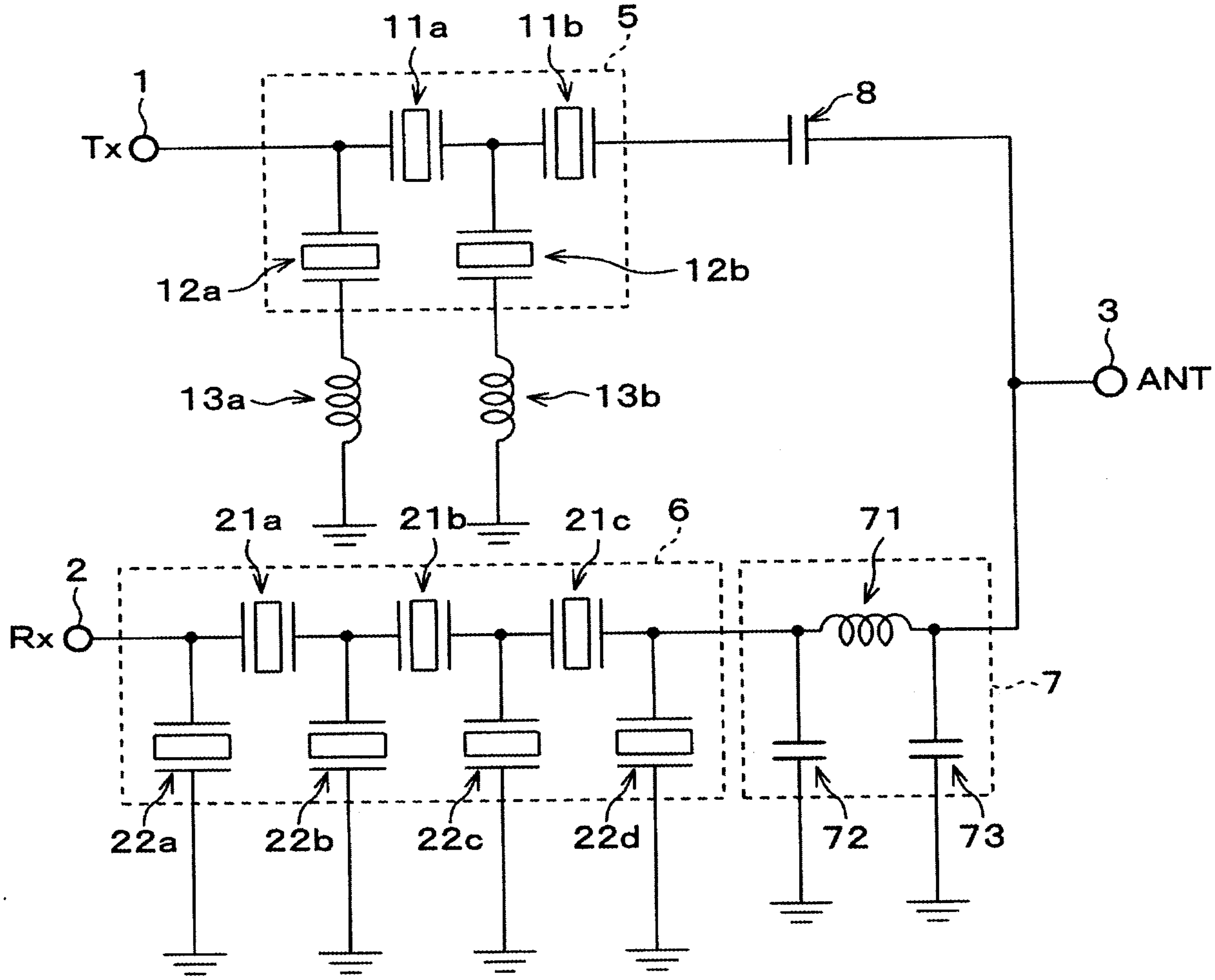
[Abstract]

[Object] A branching filter having satisfactory characteristics in which the structures of a transmission-side filter and a reception-side filter are optimized is provided.

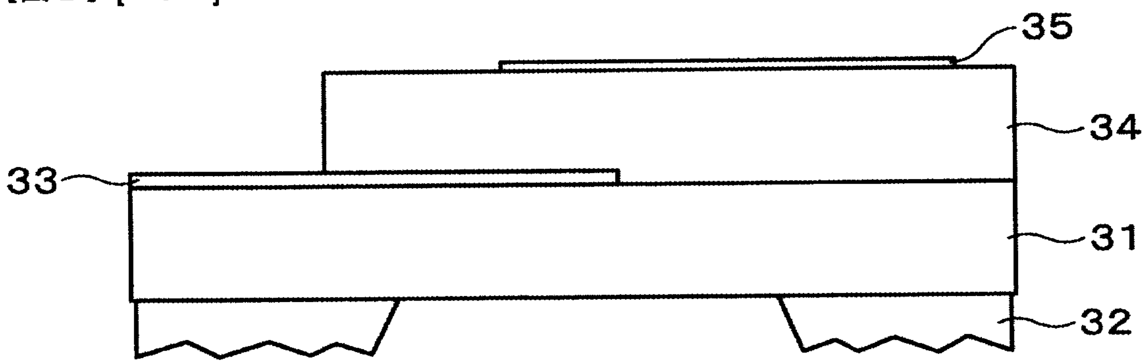
[Solving Means] A branching filter includes a transmission-side filter 5 and a reception-side filter 5 in which piezoelectric resonators 11a, 11b, 12a, 12b, 21a to 21c, and 22a to 22d including a piezoelectric thin film sandwiched between facing electrodes are disposed in a ladder type on an opening or a recess of a substrate. The transmission-side filter 5 and the reception-side filter 6 are connected to an antenna terminal 3 in parallel. The piezoelectric resonators 11a, 11b, 12a, and 12b constituting the transmission-side filter 5 and the piezoelectric resonators 21a to 21c and 22a to 22d constituting the reception-side filter 6 are different from each other.

[Selected Figure] Fig. 1

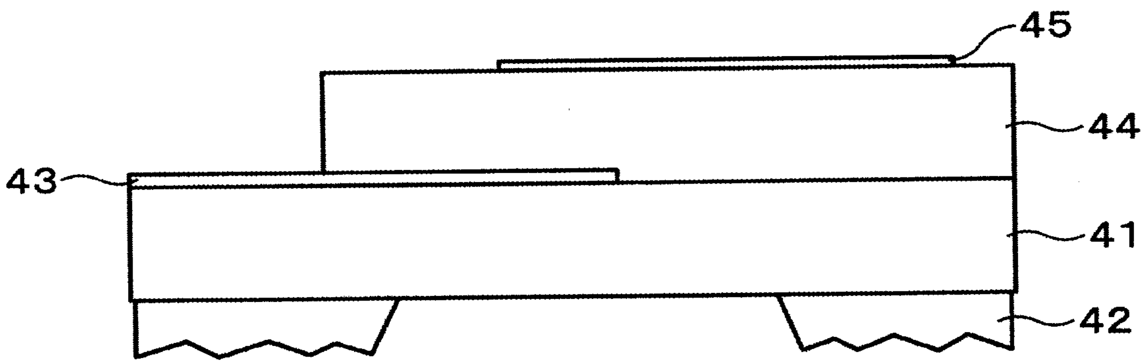
【書類名】　図面　[Name of Document] DRAWINGS
【図１】[FIG. 1]



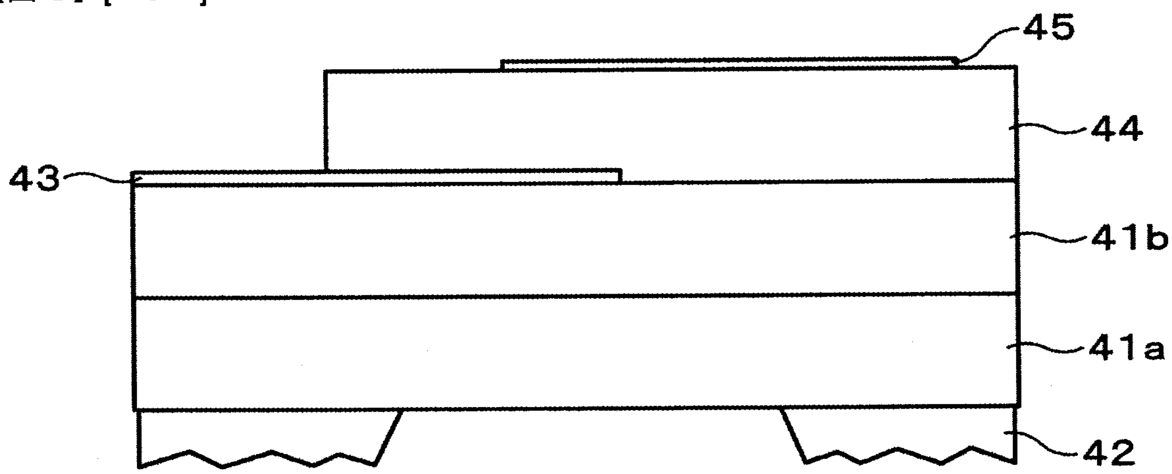
【図２】[FIG. 2]



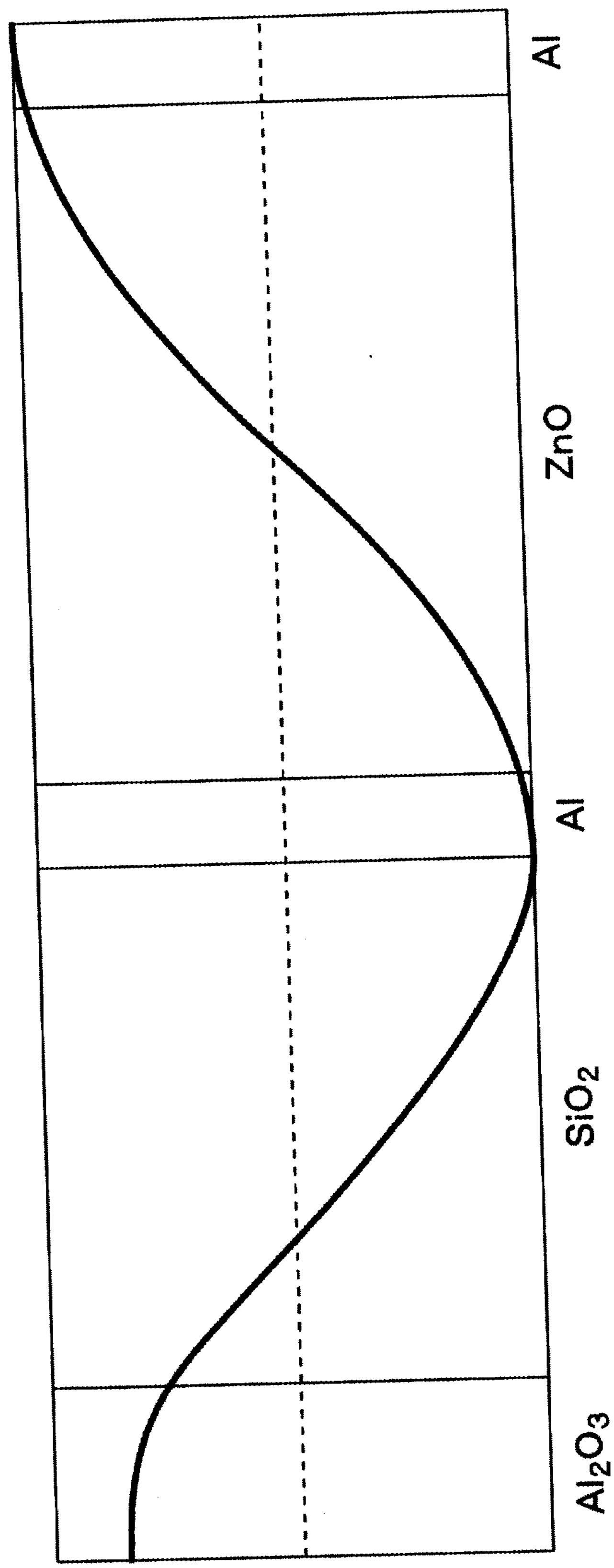
【図３】[FIG. 3]



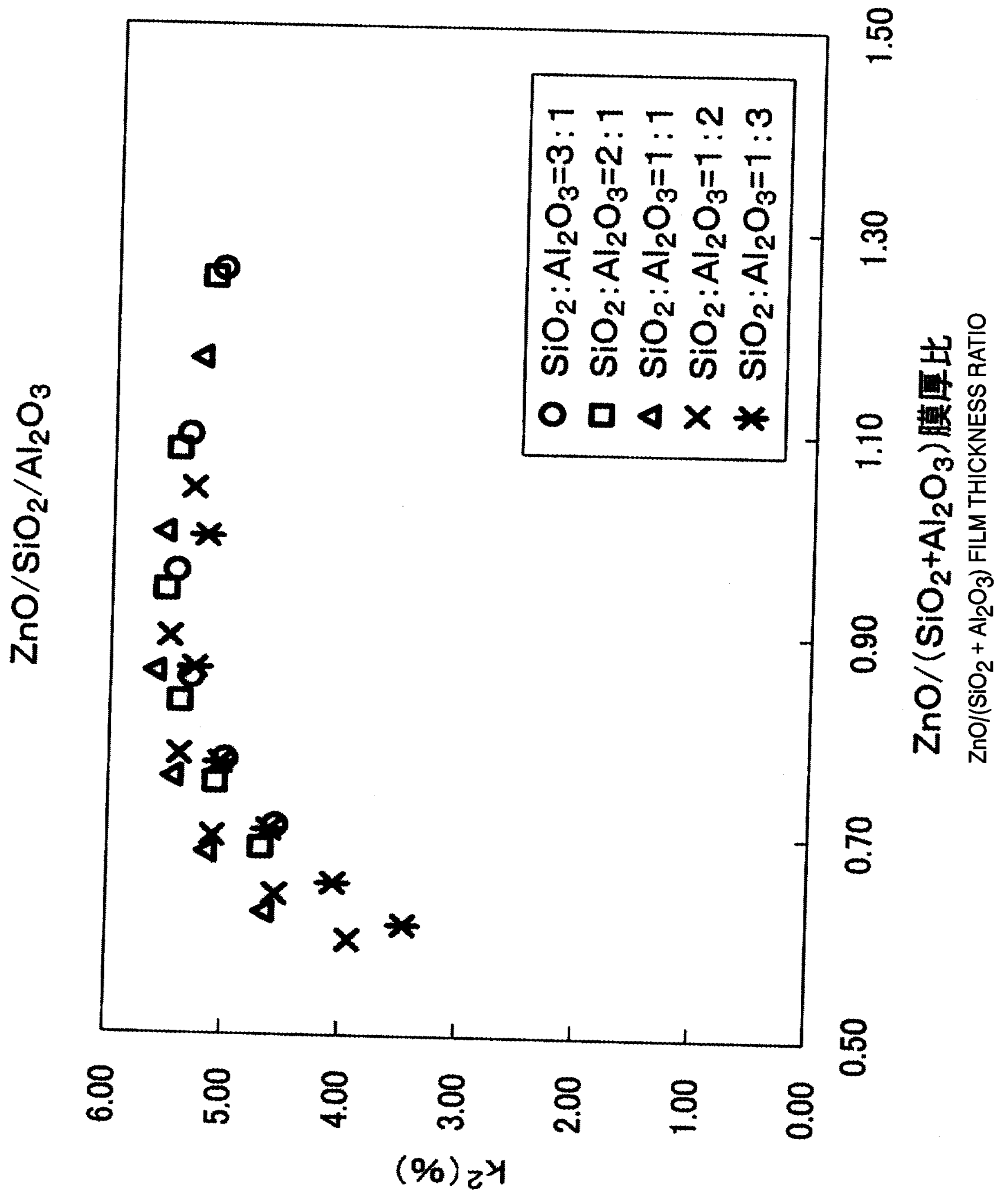
【図４】[FIG. 4]



【図５】[FIG. 5]

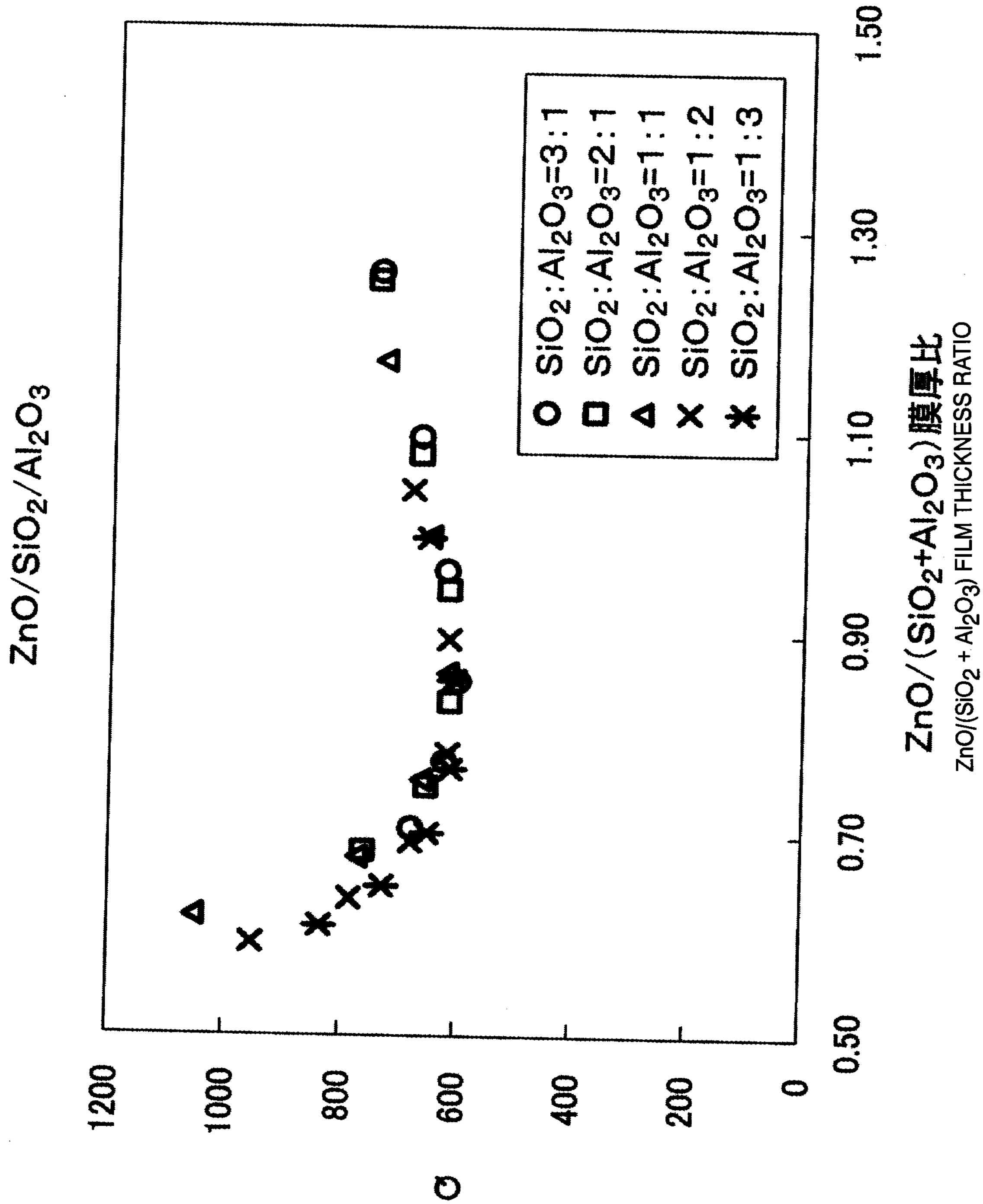


【図６】[FIG. 6]



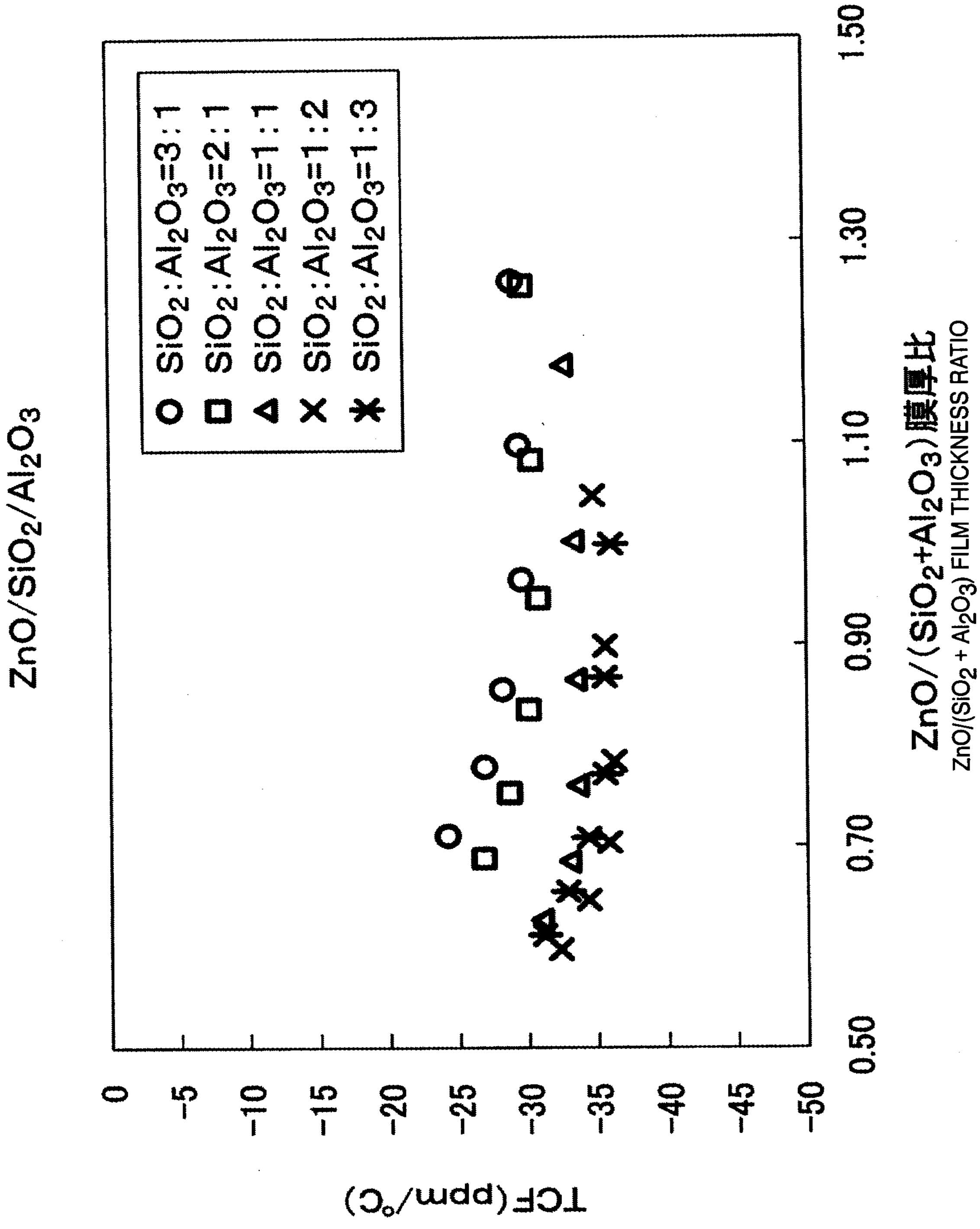
ZnO/SiO2/Al2O3
k2 (%)
6.00
5.00
4.00
3.00
2.00
1.00
0.00
0.50
0.70
0.90
1.10
1.30
1.50
SiO2 : Al2O3=3 : 1
SiO2 : Al2O3=2 : 1
SiO2 : Al2O3=1 : 1
SiO2 : Al2O3=1 : 2
SiO2 : Al2O3=1 : 3
ZnO/(SiO2+Al2O3)膜厚比
ZnO/(SiO2 + Al2O3) FILM THICKNESS RATIO

【図７】 [FIG. 7]



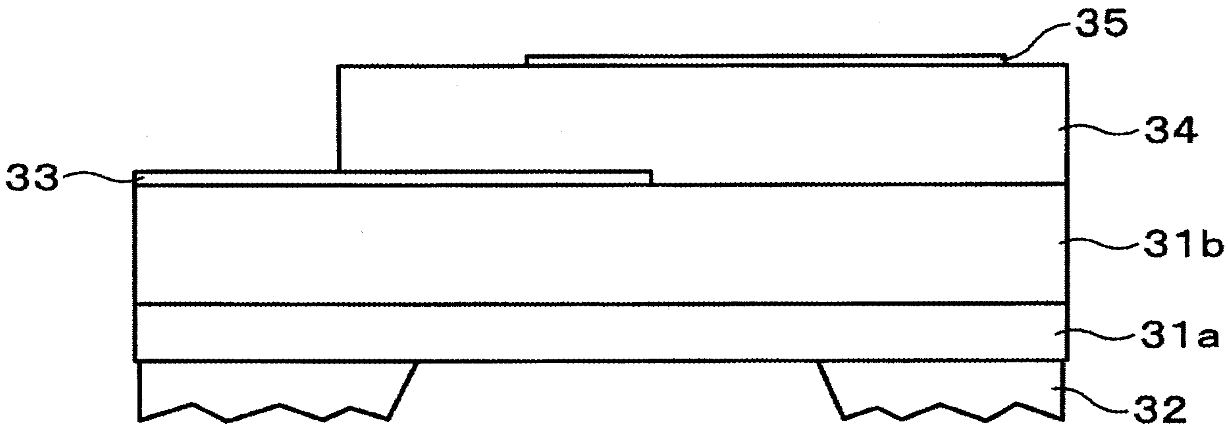
ZnO/SiO2/Al2O3
SiO2 : Al2O3=3 : 1
SiO2 : Al2O3=2 : 1
SiO2 : Al2O3=1 : 1
SiO2 : Al2O3=1 : 2
SiO2 : Al2O3=1 : 3
0
200
400
600
800
1000
1200
0.50
0.70
0.90
1.10
1.30
1.50
ZnO/（SiO2+Al2O3）膜厚比
ZnO/(SiO2 + Al2O3) FILM THICKNESS RATIO

【図８】[FIG. 8]

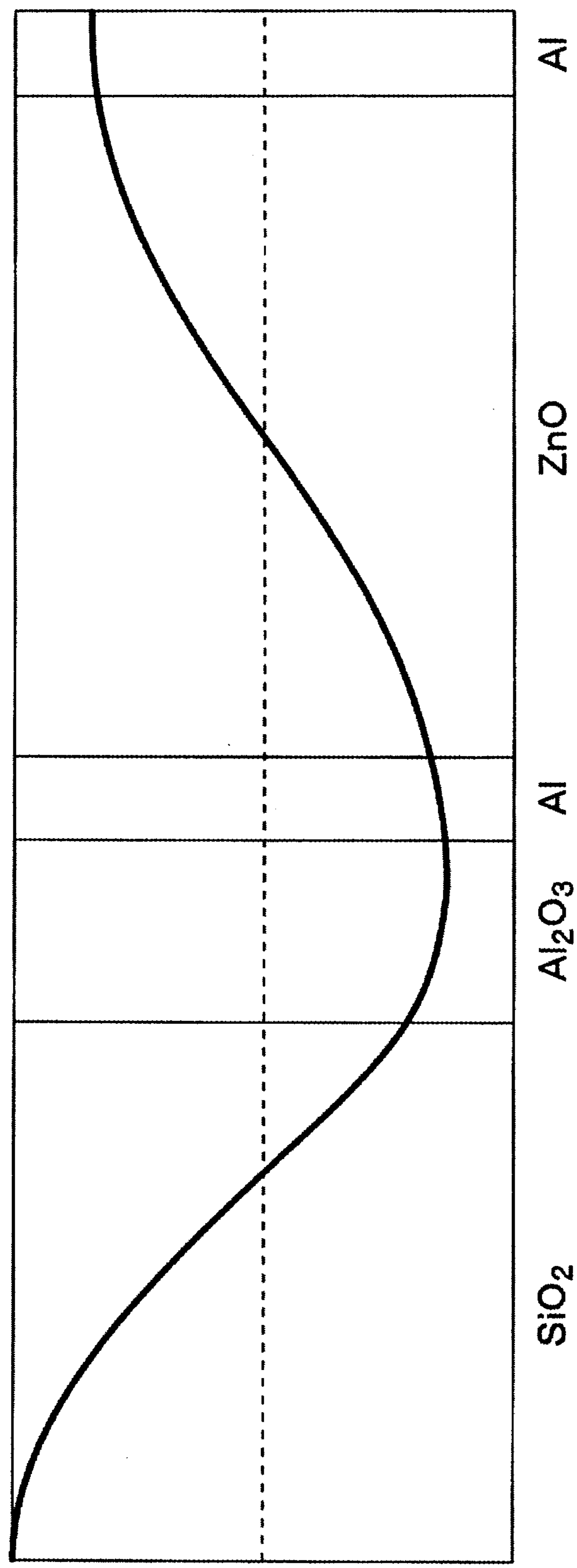


ZnO/SiO$_2$/Al$_2$O$_3$
SiO$_2$:Al$_2$O$_3$=3:1
SiO$_2$:Al$_2$O$_3$=2:1
SiO$_2$:Al$_2$O$_3$=1:1
SiO$_2$:Al$_2$O$_3$=1:2
SiO$_2$:Al$_2$O$_3$=1:3
TCF (ppm/°C)
0
-5
-10
-15
-20
-25
-30
-35
-40
-45
-50
0.50
0.70
0.90
1.10
1.30
1.50
ZnO/(SiO$_2$+Al$_2$O$_3$)膜厚比
ZnO/(SiO$_2$ + Al$_2$O$_3$) FILM THICKNESS RATIO

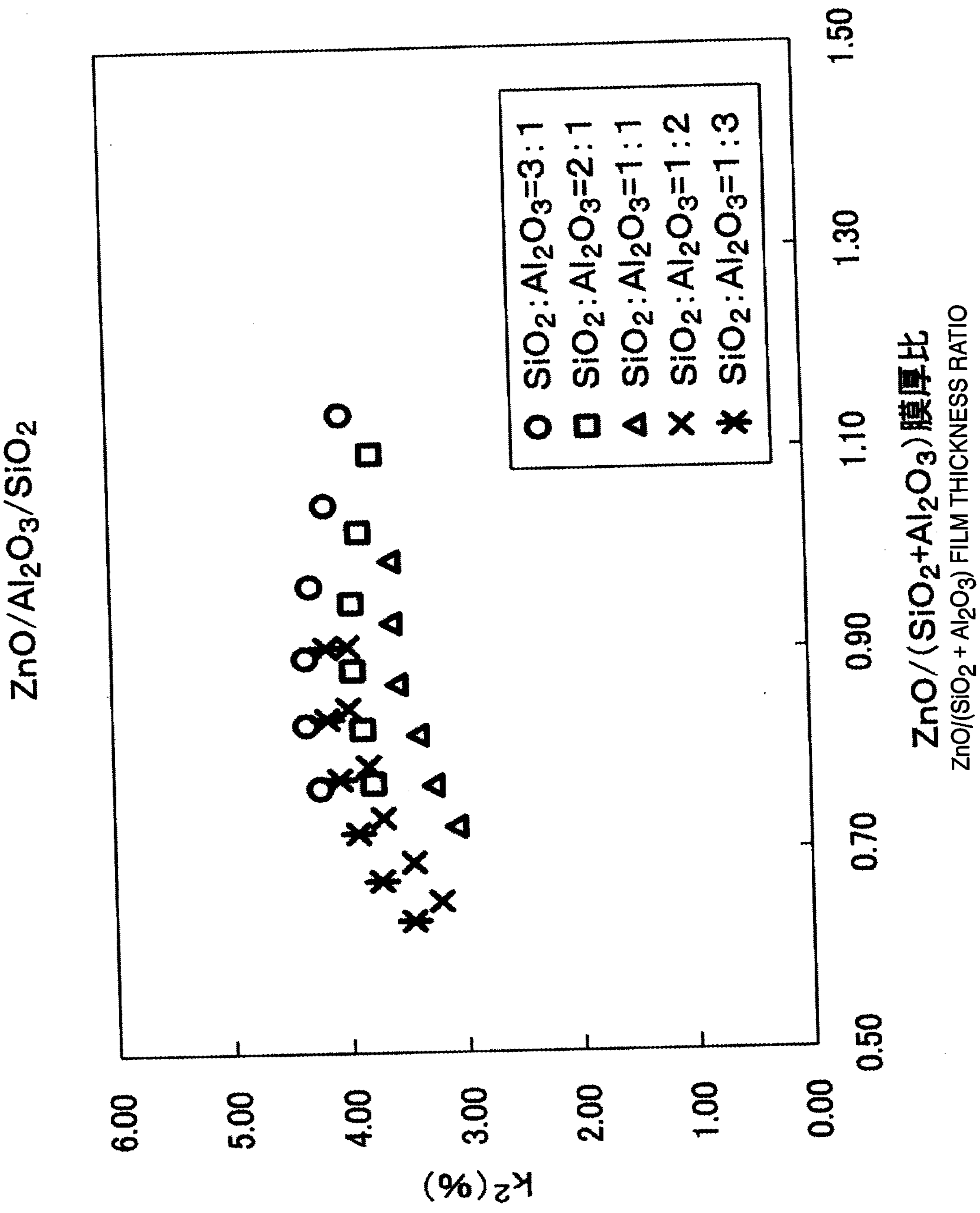
【図９】[FIG. 9]



【図１０】[FIG. 10]

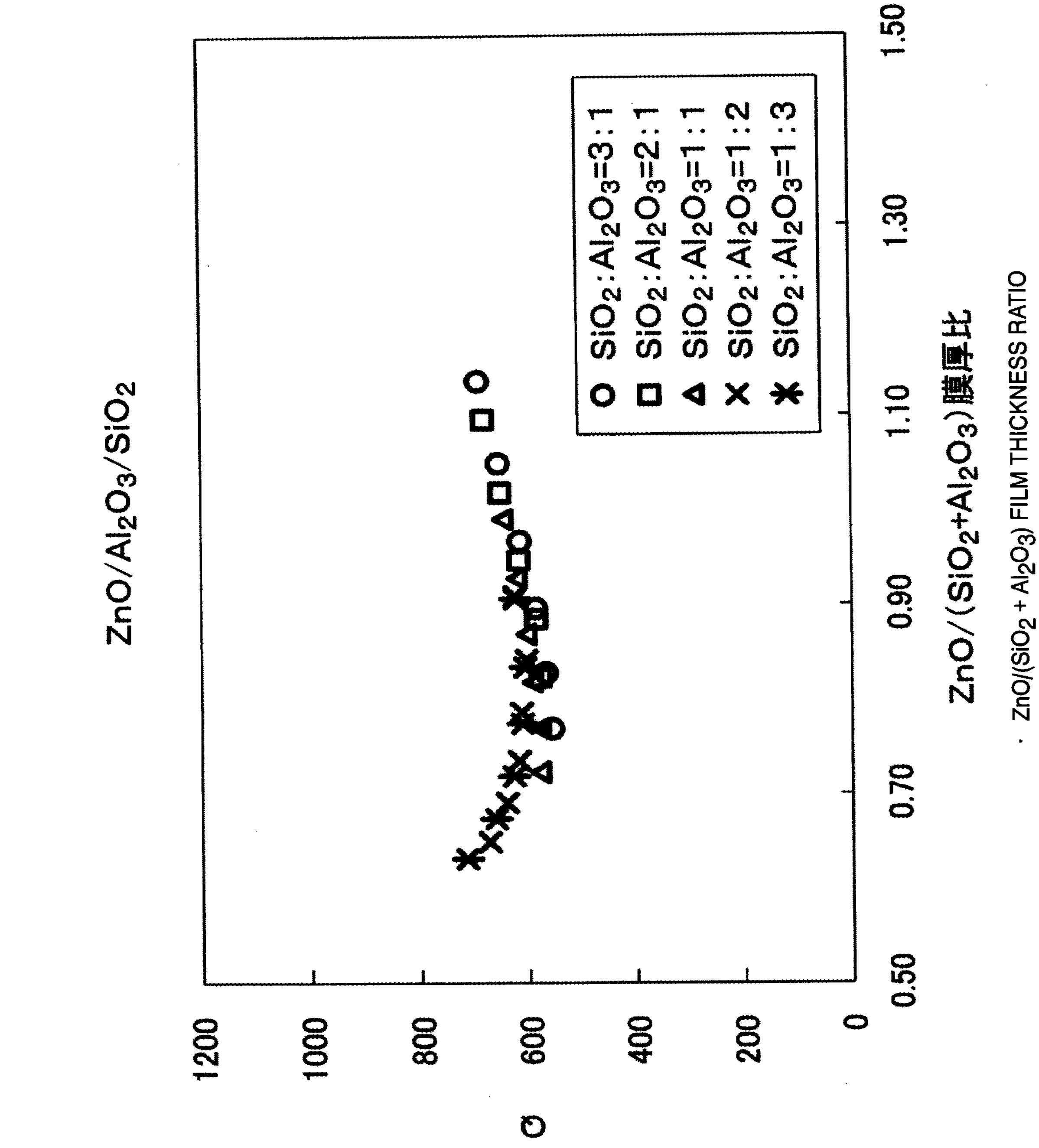


【図１１】[FIG. 11]



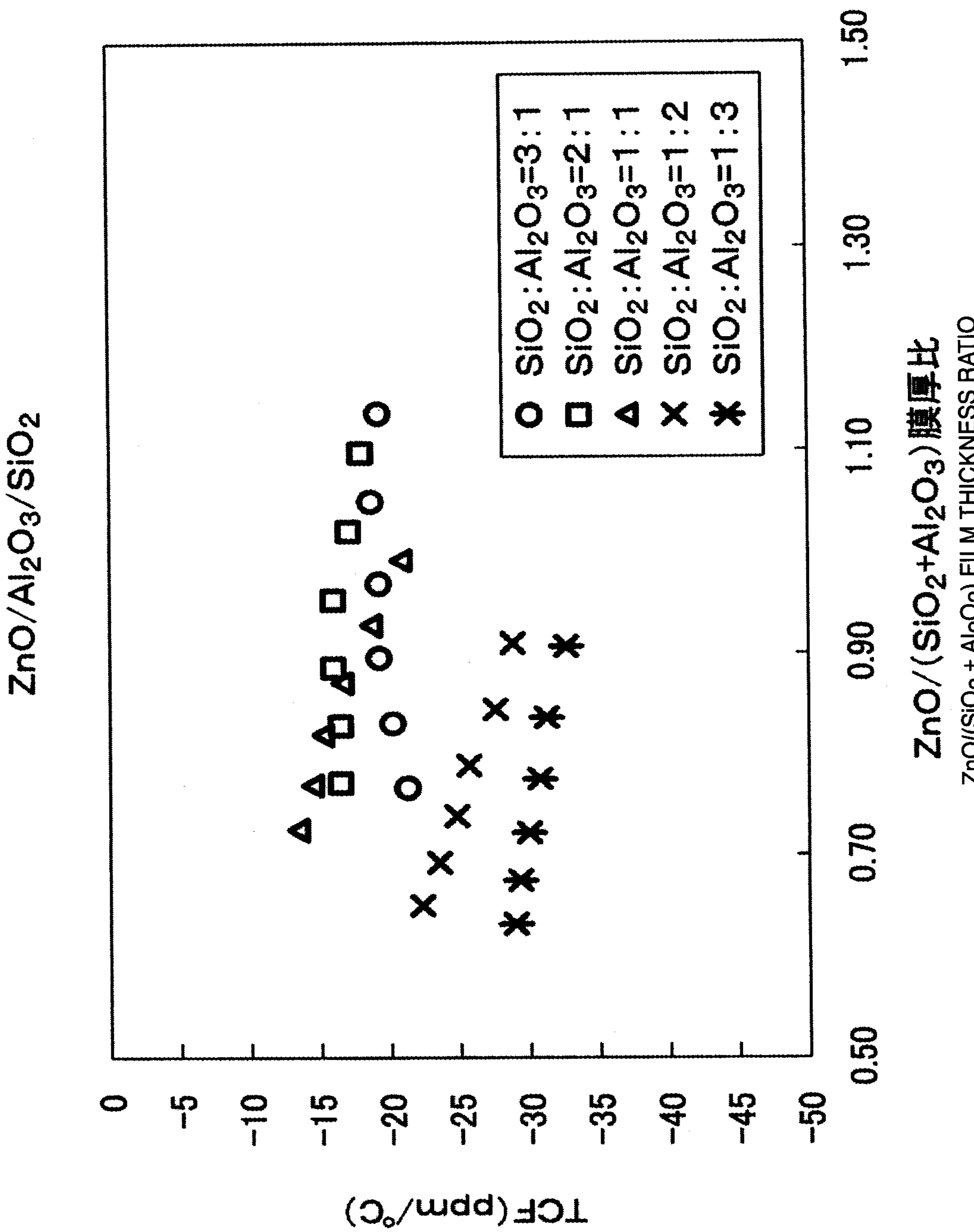
ZnO/Al_2O_3/SiO_2
k^2(%)
6.00
5.00
4.00
3.00
2.00
1.00
0.00
0.50
0.70
0.90
1.10
1.30
1.50
ZnO/(SiO_2+Al_2O_3)膜厚比
ZnO/(SiO_2 + Al_2O_3) FILM THICKNESS RATIO
SiO_2:Al_2O_3=3:1
SiO_2:Al_2O_3=2:1
SiO_2:Al_2O_3=1:1
SiO_2:Al_2O_3=1:2
SiO_2:Al_2O_3=1:3

【図１２】[FIG. 12]



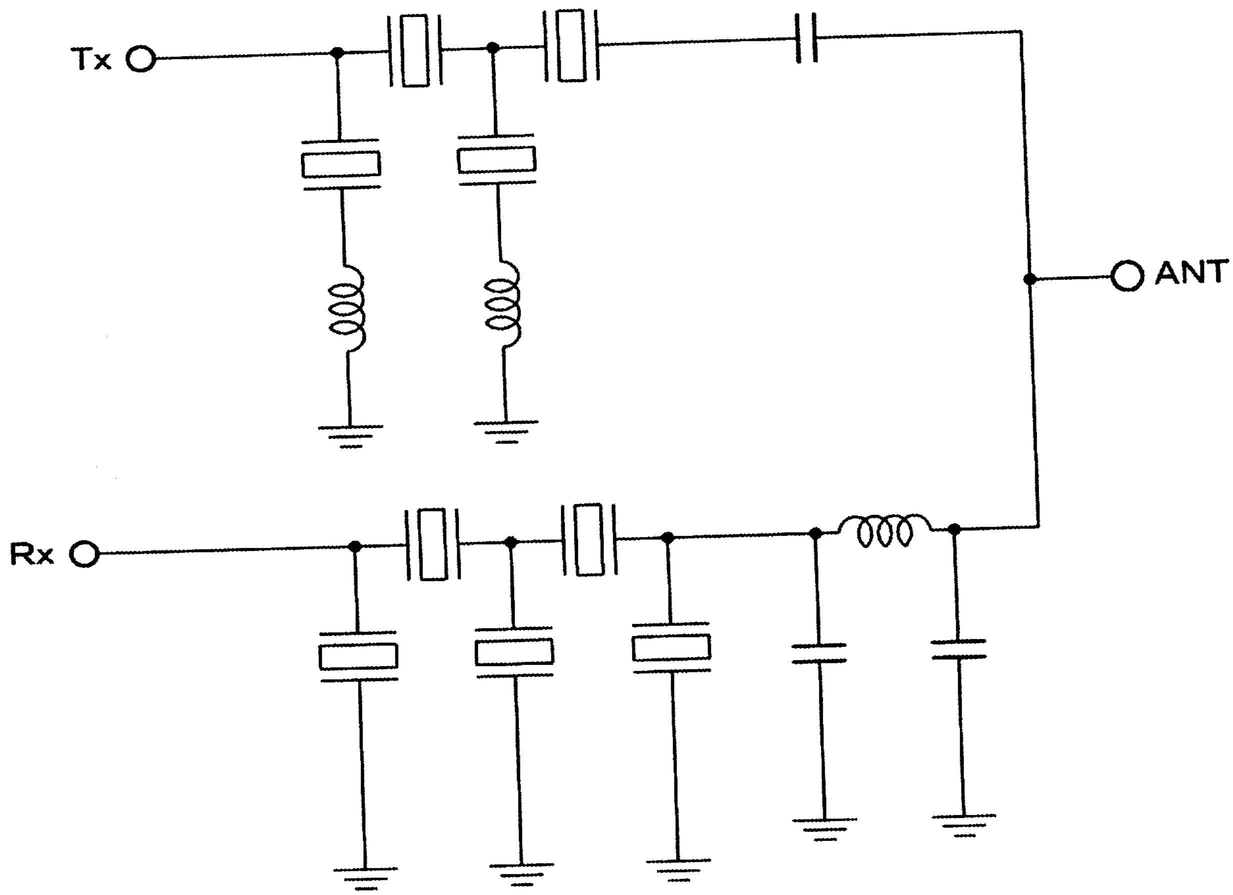
$ZnO/Al_2O_3/SiO_2$
σ
1200
1000
800
600
400
200
0
0.50
0.70
0.90
1.10
1.30
1.50
$SiO_2:Al_2O_3$=3:1
$SiO_2:Al_2O_3$=2:1
$SiO_2:Al_2O_3$=1:1
$SiO_2:Al_2O_3$=1:2
$SiO_2:Al_2O_3$=1:3
$ZnO/(SiO_2+Al_2O_3)$膜厚比
· $ZnO/(SiO_2 + Al_2O_3)$ FILM THICKNESS RATIO

【図１３】[FIG. 13]

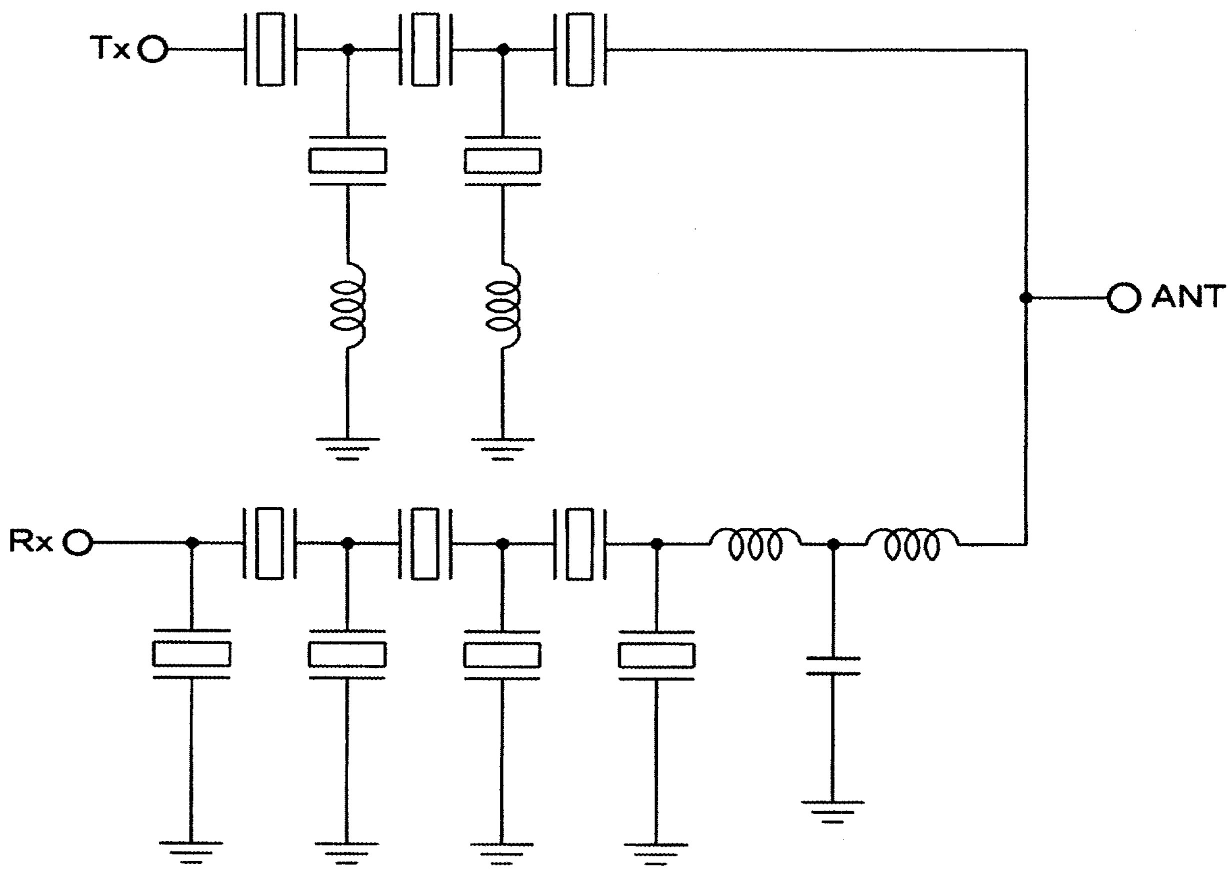


ZnO/Al2O3/SiO2
TCF (ppm/°C)
0
-5
-10
-15
-20
-25
-30
-35
-40
-45
-50
0.50
0.70
0.90
1.10
1.30
1.50
SiO2:Al2O3=3:1
SiO2:Al2O3=2:1
SiO2:Al2O3=1:1
SiO2:Al2O3=1:2
SiO2:Al2O3=1:3
ZnO/(SiO2+Al2O3)膜厚比
ZnO/(SiO2 + Al2O3) FILM THICKNESS RATIO

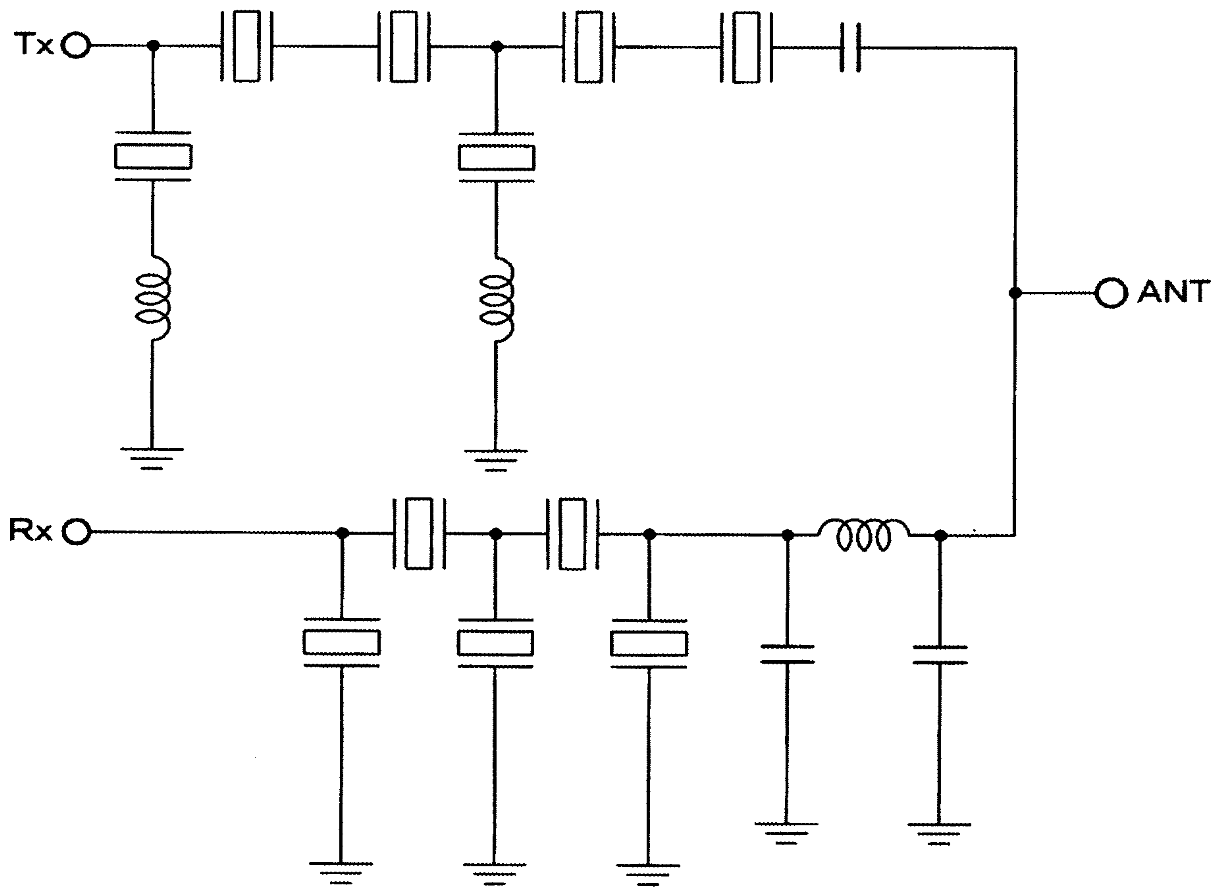
【図１４】[FIG. 14]



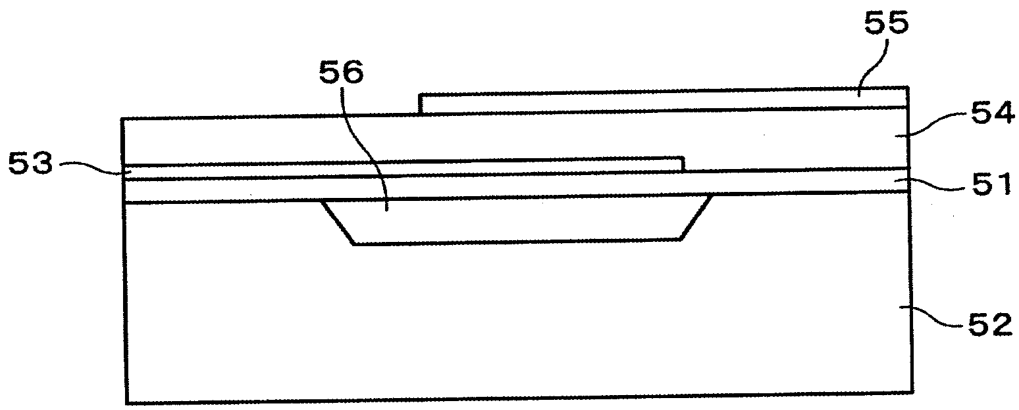
【図１５】[FIG. 15]



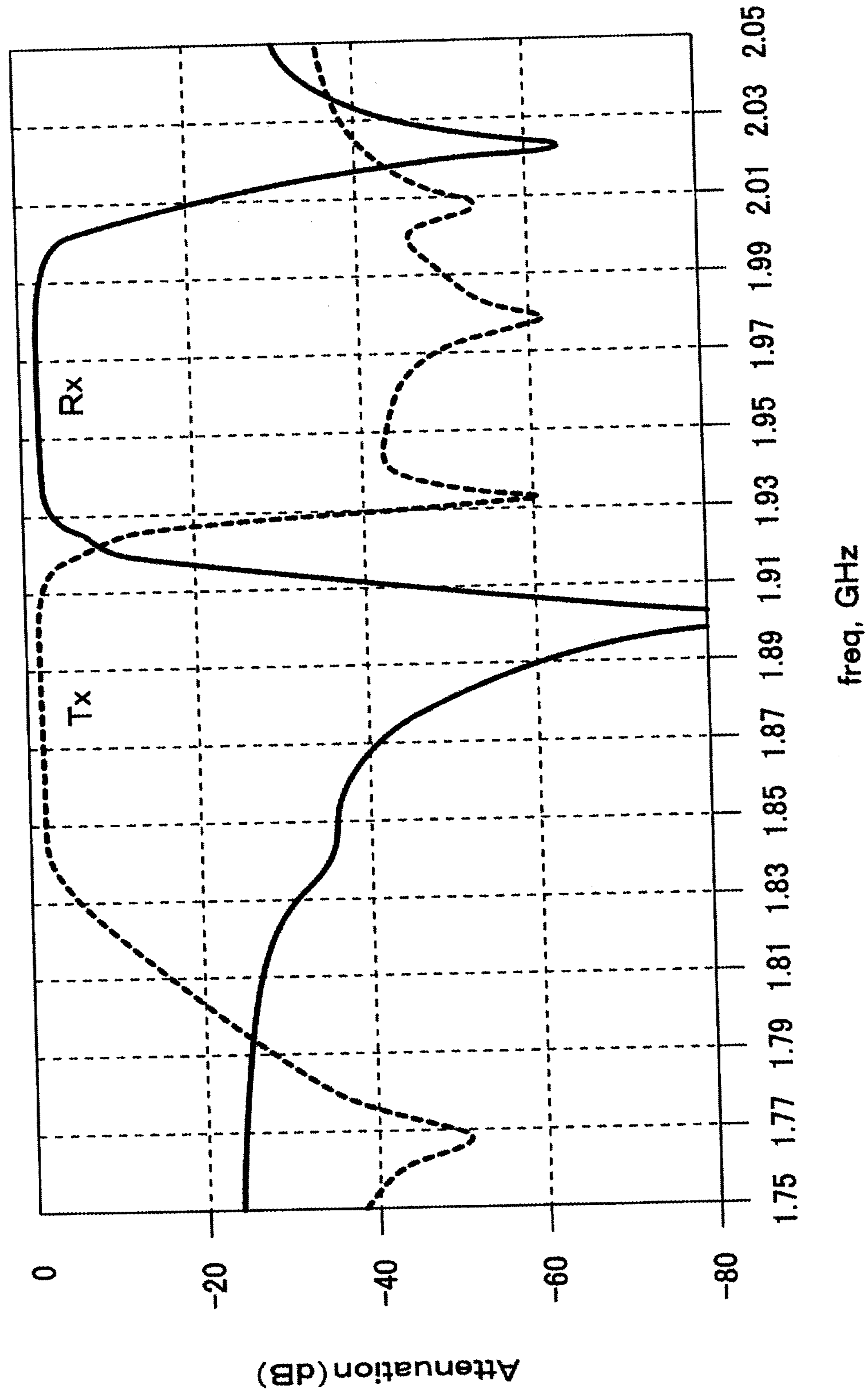
【図１６】[FIG. 16]



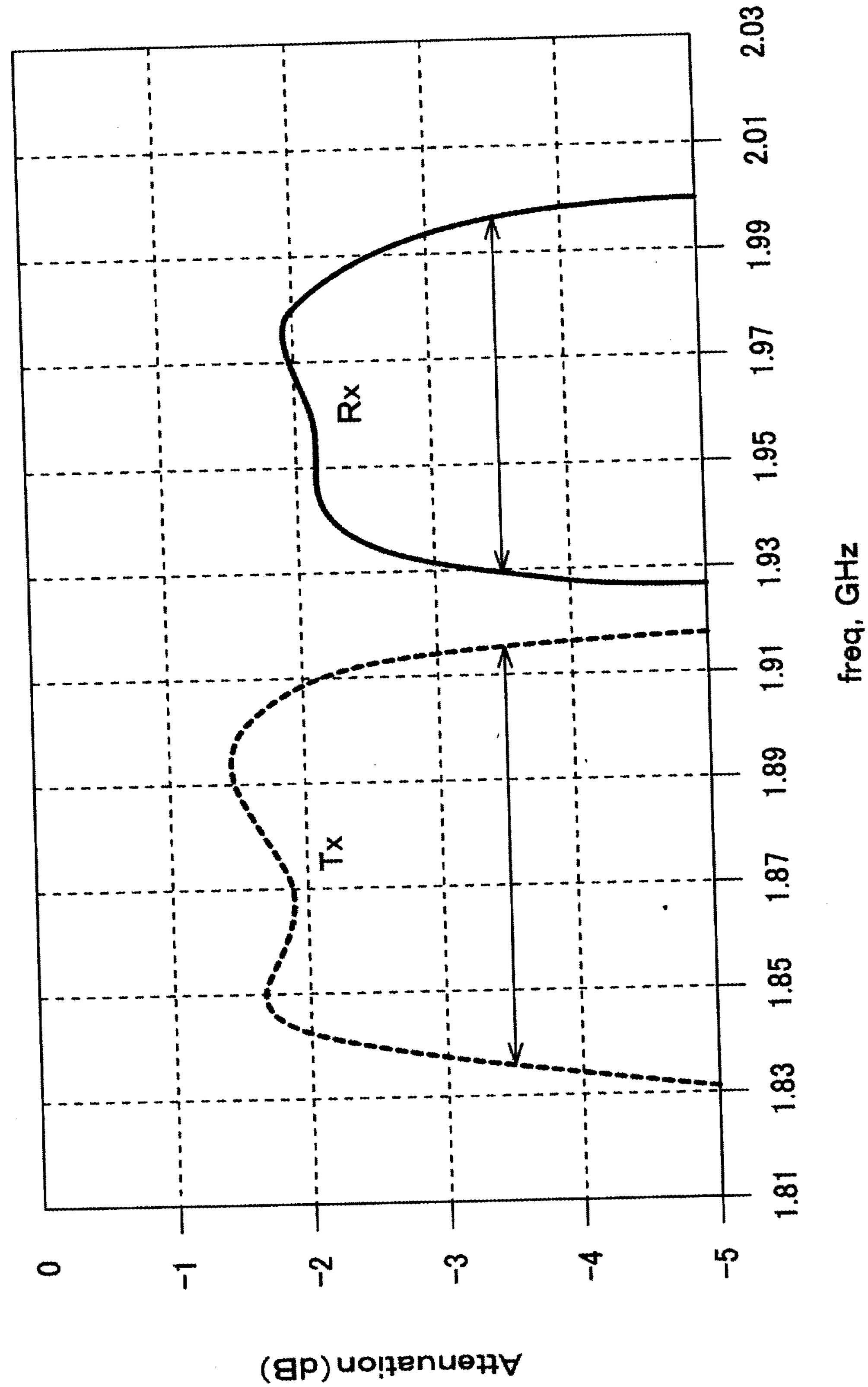
【図１７】[FIG. 17]



【図１８】[FIG. 18]

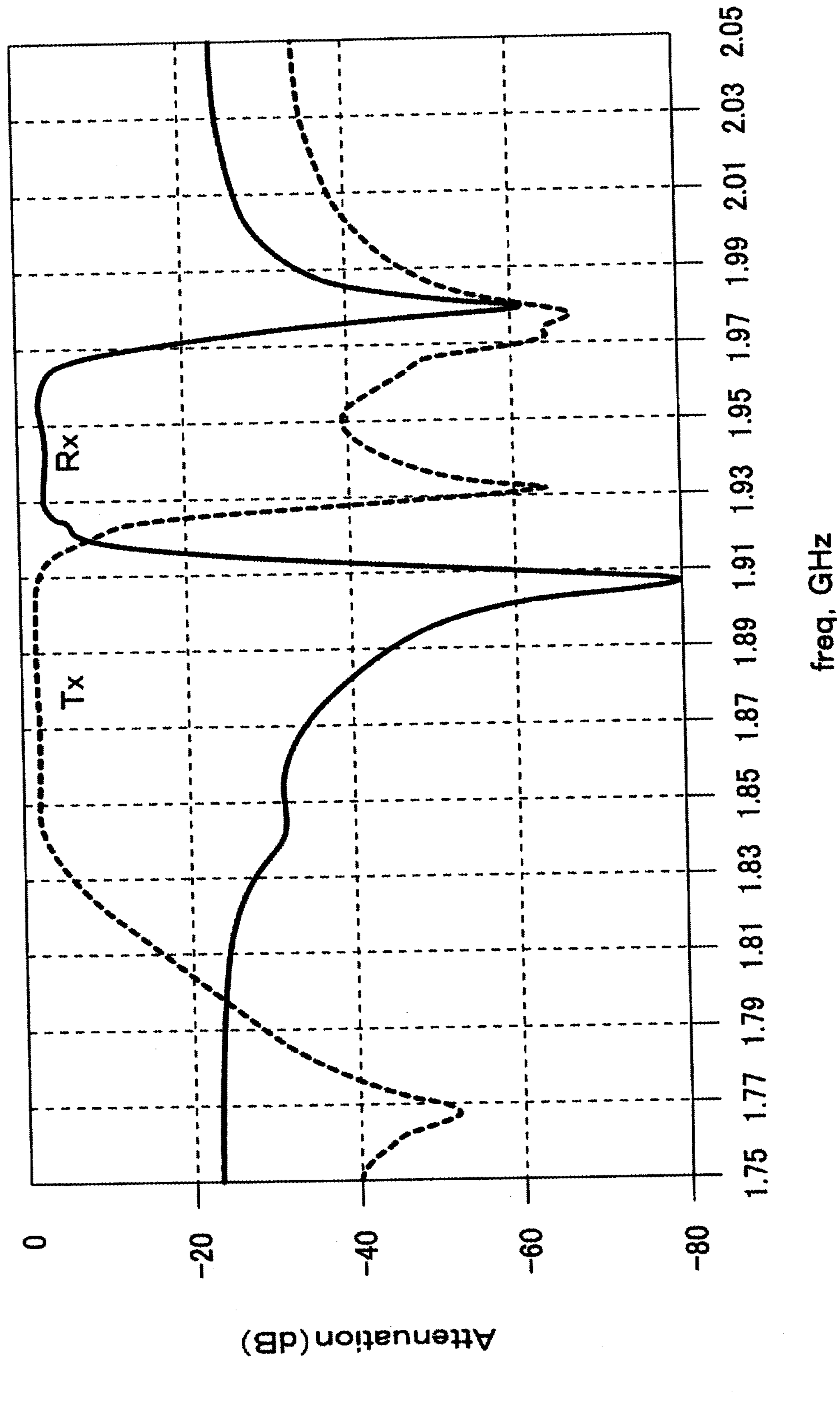

Rx
Tx
freq, GHz
Attenuation(dB)
0
-20
-40
-60
-80
1.75
1.77
1.79
1.81
1.83
1.85
1.87
1.89
1.91
1.93
1.95
1.97
1.99
2.01
2.03
2.05

【図１９】[FIG. 19]

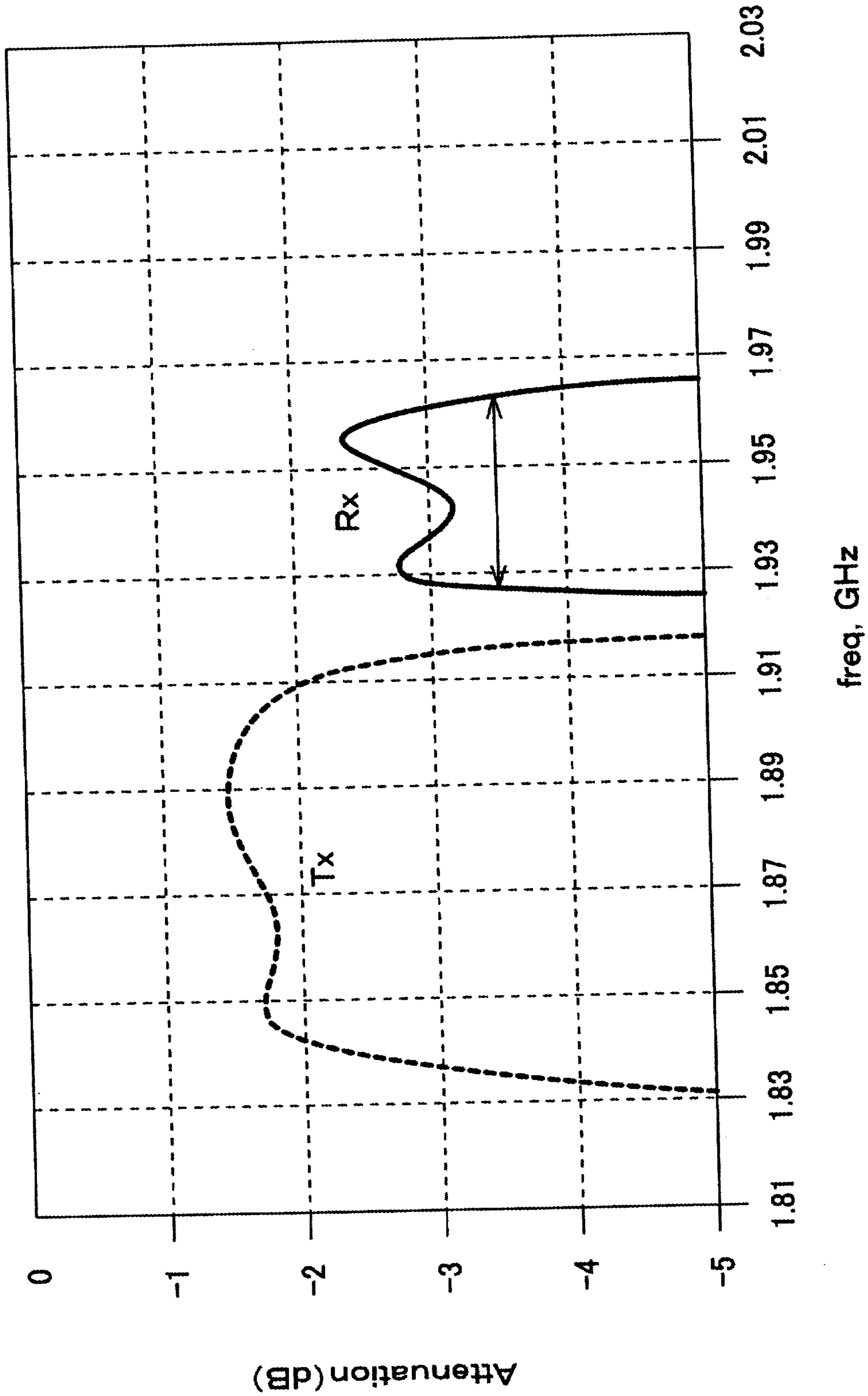


Attenuation (dB)
0
-1
-2
-3
-4
-5
freq, GHz
1.81
1.83
1.85
1.87
1.89
1.91
1.93
1.95
1.97
1.99
2.01
2.03
Tx
Rx

【図２０】[FIG. 20]


Rx
Tx
freq, GHz
Attenuation (dB)
0
-20
-40
-60
-80
1.75
1.77
1.79
1.81
1.83
1.85
1.87
1.89
1.91
1.93
1.95
1.97
1.99
2.01
2.03
2.05

【図２１】[FIG. 21]



Tx
Rx
1.81
1.83
1.85
1.87
1.89
1.91
1.93
1.95
1.97
1.99
2.01
2.03
freq, GHz
0
−1
−2
−3
−4
−5
Attenuation(dB)